Insects of Vegetable Crops in Hawaii Today

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Two years ago, almost to the day, Hawaii was attacked by Japan and the United States became actively involved in the war. The events which followed have forced on Hawaii the need for producing more of its food than it produced formerly—a necessity which has been accentuated by the increase in population through the influx of defense workers and service personnel. Because of these events, and because I have been activly engaged in advancing our knowledge of insects of food crops and their control, and in disseminating that knowledge to the public, it is perhaps natural that I should select for review "The present situation regarding insects of vegetable crops in Hawaii."

The maritime strike of 1936 demonstrated the undue extent to which Hawaii was dependent on outside sources of foods. As a result the Hawaii Experiment Station at the University made a move to re-establish the positions of Plant Pathologist and Entomologist, positions which had been allowed to lapse for many years. In 1937 I arrived in Honolulu to re-establish an Entomology Department in the Station. The Station had been without an entomologist for twenty-two years. I was charged especially with carrying on research on the insects of vegetable crops.

In the twenty-two years which had passed since Mr. Fullaway left the Experiment Station to accept a position with the Board of Agriculture and Forestry and the position of entomologist lapsed, there had been many changes. Agriculture had changed. Technical work on sugar cane was already being handled by a separate experiment station. The needs of the pineapple industry were being handled by a separate experiment station with its own entomology department. Many of the crops that the Territory had been interested in during the first fifteen years of the present century had dropped out of the agricultural picture; others were entering it. New insect problems were arising.

The first step of the new Entomology Department was, then, to determine what insect problems it would be called on to handle. True, I had been provided with a list of some twenty odd important insect problems needing attention; and the entomologists of the respective organizations of the Territory had been making observa-

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tions of considerable value over the years. But this information was inadequate. Observations soon revealed that many important problems were not on the list I had been given; other observations revealed that several insects we encountered had not even been recorded in the Territory; other insects had been recorded but were not regarded as economically important.

I shall, therefore, discuss briefly some of the aspects of this changing scene, especially as it concerns the insects, and, in particular, the new immigrants and those insects formerly of little consequence but which have become important.

The Changing Scene

Changing Agriculture

While observations made prior to the beginning of the present century have an important bearing on the field of economic entomology, applied entomology in Hawaii may be said to date from the appointment on July 1, 1902 of D. L. Van Dine to the position of entomologist in the Hawaii Agricultural Experiment Station, which at that time was supported wholly by Federal funds.

On May 18, 1903 the Division of Entomology of the newly created Board of Commissioners of Agriculture and Forestry was organized.

In August 1904 the Division of Entomology of the Experiment Station of the Hawaiian Sugar Planters' Association was created.

On December 15, 1904 a meeting was held to consider the advisability of forming a Hawaiian Entomological Society and on January 26, 1905 the new society held its first meeting. (It is of interest to note in passing that Mr. O. H. Swezey who is still one of the most active members of the Society and also the Editor of the Proceedings was present at those first two meetings and was elected a member of the first executive committee. He is the only one of the original members who is still active and regularly attends the Society's meetings.)

Thus four important entomological events took place during the four years 1902-1905 inclusive.

An examination of Van Dine's early reports gives an interesting picture of the agriculture of the day and the problems the entomologist was called on to handle. His partial lists of crops in the reports of the entomologist for 1904 (32), 1905 (33), 1906 (34), and 1907 (35) were revised and summarized in his report for 1908 (36) as "A revised list of the injurious insects of Hawaii." His list included the following twenty-six crops: Sugar, rice, coffee, taro, sisal, tobacco, cotton, cassava, sweet potato, corn, cabbage, melon, pineapple, citrus, mango, banana, avocado, fig, grape, apple, peach, guava, mulberry, strawberry, sour sop, coconut, and ornamental

and forest trees. It includes many field crops, some fruit trees and some small fruits, but only three vegetable crops. If one includes corn, which was in any case no doubt field corn, there are four vegetables. In the partial list for 1904 (32) six vegetable crops were mentioned—cucurbits, bean, tomato, corn, cabbage, and potato, and seven vegetable insects were cited.

In the report of the entomologist for 1913 by D. T. Fullaway (2) who had succeeded Van Dine in 1909, the following fourteen particular vegetable crops were mentioned: cabbage, turnip, radish, celery, parsley, carrot, potato, tomato, eggplant, cucumber, pumpkin, squash, spinach, and onion. The insects which attacked them were also given. It would appear from this longer list that vegetables were receiving greater attention. Moreover since many of the larger field crops and some of the fruits mentioned in Van Dine's earlier lists received little attention, it would appear that they were passing from the agricultural picture.

By 1915 Mr. Fullaway had resigned to accept his position with the Board of Agriculture and Forestry, and, apart from the observations and other intermittent work carried on by the entomologists of the various institutions of the Territory, research on vegetable insects as the special responsibility of an entomologist or a group of entomologists ceased until 1937 when the entomology department was re-established in the Hawaii Agricultural Experiment Station.

In the years just prior to 1937 interest in vegetable production had begun to increase. Head cabbage, Chinese cabbage, and other related crops were grown to an increasing extent, and for considerable periods supplied completely the needs of the Territory for these crops. Green bean production increased so that just before the war the Territory was producing all the beans it required. Interest in tomato production was increasing. There was also renewed interest in Irish potato production.

During the defense emergency, 1939-41, interest in sweetpotato and lima bean increased, and, following our entry into the war there was a further increase in interest in Irish potato. Through the stimulus to Victory gardens, interest in the so-called "small crops" increased.

Thus even during the past few years the agricultural picture has changed and is still changing. It is necessary to be aware of these developments since they often involve changes in the relative importance of insects too.

Vegetable insects new to Hawaii

During the years just prior to 1937 the following eight vegetable insects had been found in Hawaii for the first time:

Bean-pod borer, *Maruca testulalis* (Geyer) in 1922 by Swezey ..... [Swezey (28)]

Tomato bug *Cyrtopeltis varians* (Distant) in 1924 by Swezey ..... [Swezey (29)]
Tomato pinworm, *Keiferia lycopersicella* (Busck) in 1925 by Swezey ..... [Swezey (31)]
Vegetable weevil, *Listroderes obliquus* Klug in 1926 by Swezey ..... [Swezey (30)]
Bean capsid, *Pycnoderes quadrimaculatus* Guerin-Meneville in 1929 by Illingworth ..... [Illingworth (20)]
Pepper weevil, *Anthonomus eugenii* Cano in 1933 by Fullaway ..... [Fullaway (3)]
Datura beetle, *Lema trilineata californica* Schaeffer in 1933 (?) by Krauss ..... [Krauss (21)]
Chrysanthemum thrips, *Thrips nigropilosus* Uzel in 1935 by Sakimura ..... [Sakimura (26)]

Since 1937 the following thirteen additional insects (and mites) have been found:

Aphis rumicis Linnaeus in 1938 by Lucas ..... [Look and McAfee (23)]
Cavariella capreae (Fabricius) in 1939 by Marvin ..... [Look and McAfee (23)]
Onion moth, *Acrolepia assectella* Zeller in 1939 by Holdaway (collected by Furuya) ..... [Holdaway (14)]
Turnip aphid, *Rhopalosiphum pseudobrassicae* (Davis) in 1939 by Look ..... [Holdaway, Look and Lucas (19)]
Cabbage looper, *Autographa brassicae* (Riley) in 1939 by Lucas (collected by Akana) ..... [Holdaway, Look and Lucas (19)]
Onion aphid, *Micromyzus formosanus* (Takahashi) in 1939 by Look ..... [Holdaway, Look and Lucas (19)]
Dendrothripoides ipomeae Bagnall in 1940 by Bianchi ..... [Bianchi (1)]
Celery aphid, *Brachycolus heraclei* Takahashi in 1940 by Holdaway ..... [Look and McAfee (23)]
Myzus convolvuli (Kaltenbach) in 1941 by Lucas ..... [Look and McAfee (23)]
Tomato russet mite, *Phyllocoptes destructor* Keifer in 1942 by Holdaway ..... [Holdaway (13)]
Rusty-banded aphid, *Aphis ferruginea-striata* Essig in 1942 by Zimmerman ..... [Zimmerman (37)]
Frankliniella sp. in 1942 by Nishida ..... [Nishida (25)]
Bean thrips, *Hercothrips fasciatus* (Pergande) in 1943 by Krauss ..... [Krauss (22)][1]

Thus a number of new economic insects had entered the scene just prior to our embarking on a detailed study of vegetable insects, while several more have been recorded since we began our work.

[1] In a subsequent survey Krauss was unable to recover this insect (26).

The situation has led me to inquire "What has been happening over a longer period of time?" It has been found that since 1880 new economic insect immigrants have continually been recorded in Hawaii. Prior to 1937 the greatest number of new records of vegetable insects per five-year period, eleven species, occurred during 1905-1909 inclusive. This was the period immediately following the important developments in entomology which have already been mentioned. All these developments resulted in an increase in the number of entomological observers in the Territory and an increase in interest in matters entomological.

From 1910 onward there continued to be new records of insect immigrants but the rate of discovery fell off considerably. There was only one new record for the five-year period 1910-1914 inclusive. In the period 1915-1919 there were three new records and for the period 1920-1924 three more. One is led to the conclusion that either the new vegetable insect immigrants had to a large extent been discovered or new immigrants were not entering the Territory as frequently. Possibly both factors were operating.

What then is the explanation for the increase in records over recent years? No doubt the increased attention to insects of vegetables in the Hawaii Experiment Station has played an important part for the majority of the records are by the new group of workers. But not all the records have been made by this new group. I have concluded that the new records are in part due to the increase in vegetable importations over the past fifteen years. If this conclusion is correct, and it is supported by Mr. Fullaway, who has had more opportunity for observing the importations of vegetables than any other entomologist in the Territory, what of the future? Must we expect even more introductions? Can the quarantine service succeed in blocking them?

New problems from insects already present in the Territory

I have mentioned the new immigrant species of vegetable insects which have entered the Territory in recent years. Some of these have already made their presence felt in the crop production picture. Cabbage looper is capable of considerable injury to head cabbage at low elevations. Onion aphid, while, in general, not abundant, is also capable of serious injury when infestations are allowed to go unchecked. Turnip aphid, also, has shown, by the injury it has caused to some crops, that it is a potentially important insect. Celery aphid is the most important insect of celery today. It is capable of devastating injury if uncontrolled. We have recorded it on Oahu, Maui, and Hawaii. Tomato russet mite, which is now fairly widespread on Oahu and present also on Maui and Kauai, is capable of

complete destruction of plants if it is not controlled. All these insects must be reckoned with in vegetable production in the future.

There are other insects, however, that have been present in the Territory some time, but which have become more important through changes in the agriculture of the Territory or for other reasons not yet fully understood. Greenhouse white fly, *Trialeurodes vaporariorum* (Westw.) present in the Territory for over half a century, has become a limiting factor to green bean production in the Waianae section of Oahu—a section which formerly produced up to 58 per cent of the green beans grown on this island. (10) (12) (15). Fire ant, *Solenopsis geminata rufa* (Jerdon), which formerly was an occasional pest of the roots and stems of tomato plants, cucumber plants, and eggplants, (18) has become more important because of the increased production of these crops at the low elevations where this ant is common. Loss of crops of carrot, beet, and chard in the cotyledon stage has been shown to be due to garden flea-hopper, *Leucopoecila albofasciata* Reut. (11). This is another problem whose severity is increased by the increasing vegetable production. Prior to 1941 tomato bug was not a particularly important insect of tomato because conditions favorable to the bug were unfavorable to tomato production with the varieties that were then available. In 1941 Dr. Frazier found that "Bounty," one of his new introductions, was particularly suitable for growth under our low elevation, high temperature conditions. These were the conditions under which tomato production was difficult with the varieties formerly available. Following the introduction of "Bounty," commercial tomato production in the Territory during the six-month period of summer months, June-November, inclusive, has increased 79 per cent in two years. On Oahu, where the summer increase is most marked, production of tomatoes has advanced 264 per cent. Through this change in production of tomatoes during summer at low elevations tomato bug has now become an important factor in the growing of tomatoes (12).

The Insects of Vegetables Today

As a result of the new insect immigrants and the increased importance of many other species, the insects of vegetables today are different from those recorded at any other time in the history of the Territory.

In an insect control program it is necessary first to determine which species of insects are responsible for injury to the respective vegetables and when, where, or under what conditions injury occurs. Hawaii has no winter to speak of. Thus the low temperatures so characteristic of continental areas are not available to reduce the abundance of the crop insects. Nevertheless there are marked relationships between certain insects and climatological

zones or physiographic areas. Some are insects of low elevation; some are insects of high elevation; some are insects of the summer; some are most abundant in regions of intermediate rainfall; some are apparently little affected by climatic conditions or physiography but are affected more by abundance of host crops and especially by the sequence of crop hosts than by any other factor. Further it is necessary to determine the *group* of insects which occurs on each crop and which of them are of major importance. When the major problems have been determined, experimental work on the control of the major insects can be devised with due regard for the possible presence of other insects or diseases.

A considerable amount of knowledge has been built up on the insects of the respective vegetables. While much more work remains to be done, and while further observations will undoubtedly result in some modification of ideas held at the present time, sufficient information has been secured for the practical needs of the moment.

In the accompanying table I have listed the insects of 30 vegetables. They are grouped as major insects, submajor insects, occasional pests, and minor insects.

Major insects are those which cause major economic loss of the crop attacked unless they are controlled. They are, in general, widespread in their distribution. They are not necessarily present on the crop at all times and in all places; some are restricted as to vegetation zone and season.

Submajor insects are those insects which may cause major economic loss at times, but less severely, less often, or to a less widespread extent than the major insects.

Occasional pests are those minor insects which occasionally are present in sufficient numbers to cause marked injury.

Minor insects are those which may feed freely on or reproduce on the host crop but which do not cause marked injury to the crop.

In the observations which have been made to date some crops have received more attention than others and a more complete picture of the insects of such crops has thus been secured. Although the amount of time given to the respective crop has varied, it is probable that further observations will not lead to any marked changes in designation of the major and the submajor insects.

You will observe from the table that there is a comparatively small number of major insects for each crop—sometimes none—but a larger number of the group I have designated as "submajor." There is a relatively large number of the minor insects which occasionally are present in numbers sufficiently large to cause injury. The list of insects designated as minor is approximately the same size as that of the occasional pests. From the practical standpoint the major and submajor insects are of most consequence. Many of these, however, are not present for considerable periods.

Table 1. The Major Insects, Submajor Insects, Occasional Pests, and Minor Insects of 30 Vegetables in Hawaii.[1]

Crop	Major Insects[1]	Submajor Pests[1]	Occasional Pests[1]	Minor Insects[1]
Bean (green)	*Adoretus sinicus* *Aphis medicaginis* *Trialeurodes vaporariorum*‡ *Empoasca solana**	*Pycnoderes quadrimaculatus** *Hemitarsonemus latus** *Tetranychus* sp.* *Plusia chalcites*	*Heliothis armigera* *Veronicella leydigi* *Liriomyza pusilla* *Frankliniella* sp. *Stictocephala festina* *Solenopsis geminata** *Dacus cucurbitae*	*Aphis gossypii* *Cosmolyce boetica* *Phenacoccus gossypii* *Atractomorpha ambigua* *Cyrtopeltis varians* *Myzus persicae*
Bean (lima)	*Maruca testulalis* *Aphis medicaginis*	*Pycnoderes quadrimaculatus** Tetranychid sp.*	*Stictocephala festina* *Frankliniella* sp.* *Plusia chalcites*	*Empoasca solana** *Aphis rumicis*
Beet	*Hymenia recurvalis** *Hemitarsonemus latus**	*Leucopoecila albofasciata*§ *Empoasca solana** *Laphygma exigua*	*Nysius nigriscutellatus**	*Myzus persicae* *Plusia chalcites*
Broccoli	*Pieris rapae* *Hellula undalis**	*Adoretus sinicus* *Autographa brassicae* *Agrotis ypsilon* *Brevicoryne brassicae* *Myzus persicae* *Murgantia histrionica* *Eulota similaris*¶ *Veronicella leydigi*¶	*Laphygma exigua* *Thrips tabaci* *Plutella maculipennis**	*Laphygma exigua* *Liriomyza pusilla*
Cabbage (Chinese)	*Hellula undalis**	*Adoretus sinicus* *Eulota similaris*¶ *Pieris rapae* *Peridroma margaritosa* *Rhopalosiphum pseudobrassicae* *Myzus persicae*	*Liriomyza pusilla* *Nysius nemorivagus*† (Hawaii) *Listroderes obliquus*† (Maui, Hawaii) *Murgantia histrionica*	*Brevicoryne brassicae* *Laphygma exigua*

Table 1. The Major Insects, Submajor Insects, Occasional Pests, and Minor Insects of 30 Vegetables in Hawaii.[1]—Continued.

Crop	Major Insects[1]	Submajor Pests[1]	Occasional Pests[1]	Minor Insects[1]
Cabbage (head)	*Pieris rapae* *Hellula undalis**	*Autographa brassicae* *Agrotis ypsilon* *Eulota similaris*¶ *Veronicella leydigi*¶ *Brevicoryne brassicae* *Myzus persicae* *Murgantia histrionica* *Peridroma margaritosa*	*Atractomorpha ambigua* *Plutella maculipennis** *Listroderes obliquus*† (Maui, Hawaii) *Laphygma exigua* *Thrips tabaci* *Heliothis armigera* *Plusia chalcites*	*Liriomyza pusilla* Earth worm sp.
Carrot		*Agrotis ypsilon* *Listroderes obliquus*† (Hawaii) *Brevicoryne brassicae* *Leucopoecila albofasciata*§	Tetranychid sp. *Pseudococcus brevipes* *Aphis ferruginea-striata* *Brachycolus heraclei*	*Laphygma exigua* *Atractomorpha ambigua*
Celery	*Brachycolus heraclei*	*Plusia chalcites*	*Pseudococcus brevipes* Tetranychid sp. *Coccus viridis* *Veronicella leydigi* *Thrips tabaci*	*Aphis gossypii* *Liriomyza pusilla* *Agromyza virens*
Chard	*Hymenia recurvalis** *Hemitarsonemus latus**			*Empoasca solana** *Nysius nigriscutellatus*
Chinese spinach		*Hymenia recurvalis**	*Agrotis ypsilon* *Empoasca solana** *Leucopoecila albofasciata*	*Myzus persicae* *Nysius nigriscutellatus* *Laphygma exigua*

[1] Including Acarina, Mollusca and Annulata.
* At low elevations.
§ At onset of dry season.
¶ During wet season.
† At higher elevations.
‡ In Waianae and Lualualei, Oahu and certain other isolated places.

Table 1. The Major Insects, Submajor Insects, Occasional Pests, and Minor Insects of 30 Vegetables in Hawaii.[1]—Continued.

Crop	Major Insects[1]	Submajor Pests[1]	Occasional Pests[1]	Minor Insects[1]
Corn (sweet)	*Heliothis armigera* *Peregrinus maidis** *Aphis maidis*	*Adoretus sinicus* *Laphygma exempta* *Agrotis ypsilon*		*Amorbia emigratella* *Atractomorpha ambigua* *Carpophilus hemipterus* *Carpophilus humeralis* *Plusia chalcites*
Cowpea	*Empoasca solana**	*Aphis medicaginis*	*Maruca testulalis* *Hemitarsonemus latus**	*Heliothis armigera*
Cucumber	*Dacus cucurbitae* *Aphis gossypii*	*Apomecyna pertigera* *Empoasca solana** *Pycnoderes quadrimaculatus**	*Solenopsis geminata** *Nysius nemorivagus*† (Hawaii) Collembola sp. (Hawaii)	*Thrips tabaci*
Daikon	*Hellula undalis**	*Rhopalosiphum pseudobrassicae*	*Liriomyza pusilla* *Murgantia histrionica* *Listroderes obliquus* *Pseudococcus brevipes*	*Myzus persicae*
Eggplant	*Adoretus sinicus** Tetranychid sp.* *Hemitarsonemus latus**	*Epitrix parvula** *Aphis gossypii* *Saissetia nigra* *Anthonomus eugenii* *Contarinia lycopersici** *Frankliniella* sp.*	*Thecla echion* *Myzus persicae* *Agrotis ypsilon* *Gnorimoschema operculella* *Solenopsis geminata** *Icerya purchasi* *Phenacoccus gossypii* *Lema trilineata californica* *Trialeurodes vaporariorum*	*Heliothis armigera* *Amorbia emigratella* *Plusia chalcites* *Empoasca solana* *Macrosiphum solanifolii* *Atractomorpha ambigua*
Lettuce		*Plusia chalcites* *Empoasca solana** *Thrips tabaci** *Thrips nigropilosus*	*Pycnoderes quadrimaculatus** *Listroderes obliquus*† (Hawaii) *Heliothis armigera*	*Liriomyza pusilla* *Autographa brassicae* *Dendrothripoides ipomeae* *Laphygma exigua*

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Crop	Major Insects[1]	Submajor Pests[1]	Occasional Pests[1]	Minor Insects[1]
Lettuce (Cont'd)		*Agrotis ypsilon* *Eulota similaris*¶ *Veronicella leydigi*¶	*Trialeurodes vaporariorum*	*Macrosiphum solanifolii*
Mustard	*Hellula undalis**	*Myzus persicae*	*Pycnoderes quadrimaculatus** *Hemitarsonemus latus** *Liriomyza pusilla*	*Atractomorpha ambigua*
New Zealand spinach		*Hymenia recurvalis**	Tetranychid sp.*	
Okra	*Aphis gossypii*	*Adoretus sinicus*	Tetranychid sp.	*Empoasca solana** *Saissetia nigra* *Pycnoderes quadrimaculatus** *Frankliniella* sp.*
Onion		*Laphygma exigua* *Thrips tabaci* *Micromyzus formosanus*	*Taeniothrips alliorum*	*Acrolepia assectella* *Atractomorpha ambigua*
Parsley			*Plusia chalcites* Tetranychid sp.* *Brachycolus heraclei*	*Atractomorpha ambigua*
Pepper	*Anthonomus eugenii* *Hemitarsonemus latus**	*Laphygma exigua* *Aphis gossypii* *Contarinia lycopersici** *Frankliniella* sp.* *Myzus persicae*	*Ceratitis capitata*	*Heliothis armigera* *Thecla echion* *Phenacoccus gossypii* *Saissetia nigra*

[1] Including Acarina, Mollusca and Annulata.
* At low elevations.
§ At onset of dry season.
¶ During wet season.
† At higher elevations.
‡ In Waianae and Lualualei, Oahu and certain other isolated places.

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Crop	Major Insects[1]	Submajor Pests[1]	Occasional Pests[1]	Minor Insects[1]
Potato	*Gnorimoschema operculella**	*Plusia chalcites* *Laphygma exigua* *Macrosiphum solanifolii* *Agrotis ypsilon*	*Aphis gossypii* *Myzus persicae* *Empoasca solana** *Hemitarsonemus latus** *Nysius nigriscutellatus* *Nysius nemorivagus*† *Peridroma margaritosa* *Epitrix parvula* *Listroderes obliquus*† (Maui, Hawaii)	*Thrips tabaci* *Atractomorpha ambigua* *Heliothis armigera* *Laphygma exempta** Aleyrodid sp. *Cyrtopeltis varians* *Pseudococcus longispinus* *Lema trilineata californica* *Thecla echion*
Radish	*Hellula undalis**		*Listroderes obliquus*† (Maui, Hawaii) *Rhopalosiphum pseudobrassicae*	
Soybean		*Adoretus sinicus*	*Hemitarsonemus latus** *Laphygma exigua*	*Icerya purchasi* *Aphis medicaginis*
Spinach		*Hymenia recurvalis*	*Plusia chalcites* *Empoasca solana** *Hemitarsonemus latus**	*Myzus persicae* *Aphis gossypii*
Sweetpotato	*Bedellia orchilella* *Omphisa anastomosalis* *Euscepes postfasciatus*	*Cylas formicarius* *Herse cingulata*	*Adoretus sinicus* *Pycnoderes quadrimaculatus** *Plusia chalcites*	*Laphygma exigua* *Dendrothripoides ipomeae* *Aloha ipomoea* *Atractomorpha ambigua* *Aphis gossypii* Tetranychid sp.* *Hemitarsonemus latus** *Empoasca solana** *Aphis medicaginis*

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Crop	Major Insects[1]	Submajor Pests[1]	Occasional Pests[1]	Major Insects[1]
Sweetpotato (Cont'd)				*Macrosiphum solanifolii* *Myzus persicae*
Tahitian spinach			*Pentalonia nigronervosa* *Aphis gossypii*	Tetranychid sp. *Rhopalosiphum nymphaeae*
Tomato	*Heliothis armigera* *Dacus cucurbitae* *Cyrtopeltis varians** *Phyllocoptes destructor**	*Keiferia lycopersicella** *Epitrix parvula** *Macrosiphum solanifolii* *Aphis gossypii* *Hemitarsonemus latus** *Contarinia lycopersici** *Frankliniella* sp.*	*Gnorimoschema operculella* *Laphygma exempta* *Laphygma exigua* *Trialeurodes vaporariorum*‡ *Solenopsis geminata** *Plusia chalcites* *Agrotis ypsilon* Tenebrionid sp.	*Thrips tabaci* (important as a vector of spotted wilt) *Atractomorpha ambigua*
Turnip	*Hellula undalis**		*Listroderes obliquus*† (Maui, Hawaii) *Agrotis ypsilon* *Myzus persicae*	

[1] Including Acarina, Mollusca and Annulata.
* At low elevations.
§ At onset of dry season.
¶ During wet season.
† At higher elevations.
‡ In Waianae and Lualualei, Oahu and certain other isolated places.

The Control of Major Insects of Vegetable Crops in Hawaii

I have indicated earlier that for 22 years it was no one's special responsibility to work on vegetable insects. It was not surprising, therefore, to find from the surveys which I made during 1938 and 1939 of the literature and of conditions in the field that there was very little organized knowledge available on the vegetable insects, while the control of the insects was almost non-existent. Some attention had been given to the biological control of a few of the vegetable insects by entomologists of the Board of Agriculture and Forestry. But this line of attack, which has been so successful against several of the important agricultural insects of Hawaii, had not received the attention it deserves. Materials for chemical control were little known and only a few were available.

Nicotine sulphate, Paris green, arsenate of lead and sulphur were available in small quantities. Nicotine sulphate was not used to any great extent against insects for which it is suitable. Paris green was used mainly for cutworm baits, and occasionally as a spray on Irish potatoes. Arsenate of lead was used very little. Use of sulphur was restricted almost exclusively to the most obvious red spider infestations; it was not used as commonly or as freely as it could have been.

Pyrethrum was available in comparatively small quantities as a Japanese product known as "Imazu." The pyrethrin content of this product was not known. Moreover it was commonly used as an all-purpose spray, often wastefully and with little result. Indeed there was little likelihood of its being successful against many of the problems for which it was used. Another pyrethrum product, "Pyrocide," had just been introduced to the Territory in small quantities.

No cryolite was available. There was no calcium arsenate and no raw rotenone powder. A small quantity of a rotenone powder had been on the market at one time a few years previously but supplies had not been continued. A commercial preparation of rotenone and pyrethrum, "Foliafume", had just appeared on the local market. While it was an effective preparation for certain problems, and a very suitable preparation for small home gardens, it was comparatively expensive for use in commercial production. Moreover, as with "Imazu," it was often used as an all-purpose spray against insects not likely to be controlled effectively by it. Most of the insecticides available were small packaged preparations put out by one or two west coast insecticide firms. Many of these prepared products were mixtures put up for certain combinations of problems present in various sections of the mainland and not necessarily of any particular use for Hawaii.

The lack of insecticides and the small use to which those available were put were no doubt due to the fact that until our own

experimental work began in 1938 there was no satisfactory basis for recommendations, importation, distribution and use of the respective insecticides.

The situation is well illustrated by the following facts. In 1913, Fullaway (2) wrote regarding cabbage webworm, even then considered to be a serious pest of cabbages and related plants, "Little can be suggested in the way of remedies as all the insecticides experimented with by Marsh failed to give appreciable results." In 1938, twenty-five years later, there were still no remedies available; moreover the vegetable growers still referred to the occurrence of cabbage webworm as due to the presence of a "sick wind" regarding which nothing could be done!

Today the ten or twelve crops which are severely attacked by cabbage webworm can be grown and are being grown satisfactorily without fear of the "sick wind," since we have demonstrated experimentally that rotenone dust and cryolite dust will control cabbage webworm satisfactorily.

In the table which I have just presented I have given part of the information necessary to a satisfactory program of research on control. Until the major and submajor insects have been determined and the relative importance of each insect on each crop has been evaluated, a program of research is likely to result in considerable loss of time and a good deal of misdirected effort. From the evidence on major and submajor insects it is possible to determine which are the particular insects calling for special experimentation and which are the "Key" problems on each crop. Moreover in planning a control program it is necessary to know something of the disease problems likely to be present on the respective crops, and whether any of them are also "Key" problems which must be reckoned with in the insect control program. Further it is also necessary to know the relative importance of "Key" insect problems and "Key" disease problems.

A few particular examples will make my point clearer.

Head cabbage has no regular major disease problems comparable in power to destroy a crop with the insect problems.[1] Thus experimentation could proceed on the insect problems with little or no thought to the possible disease problems. Moreover it has been determined that the key problems on this crop are cabbage webworm and cabbage butterfly. Further, the relative importance of these two key problems will depend on the locality and the season; at elevations below 1,000 feet, and especially in the summer months, cabbage webworm will be the more important key problem followed

[1] This was the situation at the time our work on the control of cabbage insects began. However, black rot, a bacterial disease, is now quite common in Hawaii, and causing considerable damage in some sections. Since this disease is bacterial and not likely to be affected by chemical control measures applied to the plant, the situation regarding the insects remains essentially as it was before black rot became prevalent.

by cabbage butterfly in a secondary place. At elevations above 1,000 feet cabbage webworm will be negligible and cabbage butterfly will be the key problem. At elevations of 4,000 feet cutworms are relatively important but do not rank as key problems.

Tomato has a number of insect problems from which it may suffer considerably, and, under humid conditions, has certain fungus diseases also. (We can omit the virus diseases from our present discussion since in the light of present knowledge they are not likely to be controlled or prevented by a program of chemical control in the near future.) Until the key problems are determined the control program may be aimed at any of eighteen species mentioned in the first three categories of Table 1 and capable of serious injury to the crop.

With the determination of the major insects and evaluation of corn earworm and melonfly as key problems the research program has been directed into these two main channels with the fungus diseases subsidiary key problems under wet conditions and the other insect problems subsidiary to the key problems. When control of the key insects is secured, many of the subsidiary problems are taken care of automatically by the control measures for the key problem while control of other subsidiary problems is incorporated with the measures for the key insects.

Celery is an example of yet another type of crop. On this crop the key problems are fungus diseases. Even though there are on celery two important insects, celery aphid and garden looper, control measures for these two insects are secondary and incorporated with those aimed at the diseases.

Study of the vegetable insects and research on their control has followed two governing principles, first the importance of the crop to the community and second the determination of the key problems on the important crops. Before the defense emergency the most important vegetable crops were tomato, head cabbage, green bean, and Irish potato. During the emergency period sweetpotato, carrot, cowpea, Chinese cabbage, lima bean, and sweet corn were added to the list of important crops. Following our entry into the war, lettuce, radish, chard, beets, celery, and other miscellaneous vegetables have been added because it became necessary for the Territory to produce more of its own perishable greens and, moreover, it became necessary for the home gardener to contribute his effort.

When possible we have utilized the biological control method in collaboration with entomologists of the Board of Agriculture and Forestry. But we have not had time, staff, or funds adequate to the needs of a satisfactory biological control project. It has been necessary to secure some measure of control in the minimum of time and we have secured it, in the main, by means of chemicals.

The results of much of the experimental work to date on the control of major insects have already been summarized in various progress notes, annual reports, and circulars of the Hawaii Agricultural Experiment Station and the Extension Service, and in papers presented before the Hawaiian Academy of Science (4) (5) (6) (7) (8) (9) (12) (15) (16) (17) (19). I shall not spend time here to discuss the experimental work in detail but shall restrict myself to mentioning briefly some of the more outstanding results.

Tomato

In 1937 the opinion was commonly held by agriculturists that tomato bug, *Cyrtopeltis varians,* was likely to be a limiting factor to tomato production in Hawaii. In the years immediately following the establishment of the Entomology Department we were able to show that tomato bug is primarily an insect of low elevations and especially of the summer months. With the varieties of tomato then available, satisfactory commercial production of tomatoes was apparently not possible during the summer months at low elevations; the crop was commonly grown at elevations of 1,000 to 2,000 feet, and when grown at low elevations was produced in the winter months only.

With such a system of tomato production, tomato bug was not a serious problem because tomatoes were produced mainly in regions where the importance of the bug was negligible.

Up to 1939, 50 per cent of the tomato crop was commonly lost through corn earworm attack in spite of attempts to control it with sprays. In 1940 we established a control for corn earworm by means of cryolite and worked out combination treatments for this insect and others together with a control for fungus disease.

Corn earworm on tomato is no longer a nightmare to the farmer. It is now controllable to an extent approaching 100 per cent by means of cryolite, provided timing of the applications is satisfactory and application is thorough.

I have already referred to the increased importance of tomato bug following the introduction of the variety "Bounty." We have shown that tomato bug is controllable by means of pyrethrum, rotenone, and nicotine especially when applied in dust form and also by "Lethane." Because of the present world shortage of pyrethrum and rotenone we are concentrating on such nicotine dusts as will be compatible with cryolite. To date we have secured very satisfactory results with a nicotine-talc dust but our work is still in progress.

Lima bean

A satisfactory control for bean-pod borer, *Maruca testulalis,* has been found in cryolite. Combination treatments of cryolite plus

nicotine or cryolite plus sulphur or all three materials will take care of most insect problems encountered on lima beans.

Cabbage

In normal times most of our head cabbage and Chinese cabbage came from the islands of Maui and Hawaii where cabbage is grown at elevations of 2,000 feet to 4,000 feet. At these elevations cabbage webworm is not a problem; it is an insect of the low elevations.

With a cessation of inter-island shipments of vegetables following the attack on Pearl Harbor and the attempt to grow cabbage on Oahu, where arable lands are all below 1,000 feet, cabbage webworm has been a serious problem. It attacks the growing point and may ruin the plant completely. It attacks, in addition to head cabbage, broccoli, Chinese cabbage, spoon cabbage, mustards, turnip, daikon, radish, and various Oriental crucifers.

We have found that either rotenone or cryolite will control this insect. In general dusts are superior to sprays. As a result of these findings these crops can now be grown under an increasingly wide range of conditions under which it was formerly difficult to grow them.

The cabbage butterfly, a second important insect of cabbage, broccoli, and related plants, has been controlled by means of rotenone and also by arsenate of lead. Arsenate of lead has the greater powers of retention and, in commercial production, can be used in the early stages of growth so as to conserve rotenone. In the later stages of growth, rotenone only should be used. This is a safe nonpoisonous insecticide which can be used by home gardeners on cabbage and broccoli throughout the growth of these crops.

Sweetpotato

We have determined two satisfactory controls for sweetpotato leaf miner—a spray of diesel oil emulsion plus nicotine sulphate and a Paris green spray. (Diesel oil emulsion is the oil emulsion developed by Dr. Carter of the Pineapple Research Institute for control of pineapple mealy bug.)

Green beans

We have worked out satisfactory controls for bean leafhopper, *Empoasca solana* De Long and bean capsid, *Pycnoderes quadrimaculatus,* pyrethrum plus sulphur dust, or sulphur dust alone for the leafhopper, nicotine or rotenone for the capsid. The quantitative records for a single experiment on the control of bean leafhopper involved over 121,000 leafhoppers.

The Chinese rose beetle which consumes the leaves has been in Hawaii for nearly half a century. Because the problem is complex and has many angles to it, time will not permit me to discuss it in detail. Suffice it to say that we are making good progress with it. We have shown that of materials studied to date, arsenate of lead is the only material that has any marked control on it. We are working on the correction of spray burn from arsenate of lead. Meanwhile we are continuing the search for additional materials, that will control the beetle, that do not have the weaknesses of arsenate of lead.

Beet and Chard

For beet and chard we have developed a satisfactory combination treatment which will give almost 100 per cent control of the two major insects—beet webworm and broad mite, and in addition bean leafhopper should it be present.

Corn

The mineral oil method of controlling corn earworm in sweet corn has been studied. It has been found that under Hawaiian conditions a modification of the method used in the mainland United States is necessary, for addition of insecticides to the oil causes a considerable amount of silk rotting.

Pepper

As a result of our finding that a combination treatment of cryolite and sulphur for pepper weevil and broad mite will control these two devastating pests of pepper, pepper production in the Territory is increasing markedly.

All these developments are causing vegetable production to be placed on a more satisfactory basis. Not all the insect problems, however, are solved yet. Improvements in the control measures already developed can undoubtedly be made. But one can say, even now, that satisfactory measures of control have been developed for so many of our vegetable insects, that insect depredations can no longer be said to contribute a limiting factor to vegetable production.

The extent to which insect control has progressed in the past few years can be gauged in some measure by the insecticide sales. In 1938 when we tried to secure cryolite for our experimental work it was necessary for us to order it direct from the manufacturer. Our first rotenone was secured from Dr. Carter who had obtained a small quantity of timbo from Dr. Schmidt who purchased it in Brazil. Rotenone has proved to be the best, all round safe insecticide, for home gardeners who know little of the principles of insec-

ticidal control or of the precautions necessary in using insecticides likely to be poisonous to human beings. A combination dust of rotenone and sulphur is even better and is the best, safe all round insecticide mixture for use in home gardens in Hawaii. But supplies of rotenone are limited and the world shortage is already telling on local supplies.

The success which has attended our investigations demonstrating the value of cryolite for so many insect problems is reflected in the imports of cryolite to Hawaii over the past few years.

The importation of cryolite into Hawaii rose from nil in 1939 to 3,615 pounds in 1940 and to an average of 30,395 pounds per annum in 1941 and 1942. The sales in 1943 will be more than double the sales of last year.[1] County agents and farmers alike speak in glowing terms of the value of cryolite. Often have I had the remark made to me that cryolite is the most valuable single insecticide available at the present time in Hawaii for use in commercial vegetable production.

Conclusion

I have traced the developments in the control of vegetable insects from the beginnings of applied entomology in Hawaii at the opening of the present century. I have traced them through the changing agriculture of the period, and the change of entomologists responsible for vegetable insect work through the period of lessened interest in the insects of vegetable crops to the present period of interest in vegetables for survival. I have touched on the changing scene as regards the insects present, the new insect immigrants and the new problems developed with changed conditions. I have mentioned briefly the control measures developed for many of our important insects. As time goes on, we shall undoubtedly bring more of the insects under control. The picture at present is bright. Nevertheless there is one aspect of the picture that needs watching. We are in very truth at the cross roads of the Pacific. We already possess economic insects from all parts of the earth. Commerce is increasing. Air transport has increased enormously. Since the Territory established its plant inspection and quarantine service in 1903 forty-three new vegetable insects have been recorded in Hawaii and thirteen of them have been recorded since 1938. If 43 species can become established in spite of a plant inspection and quarantine service it is not too much to say that increased vigilance will be needed in the years to come when normal trade is resumed and commercial air services continue to expand.

If, as I have suggested earlier, the increase in occurrence of new immigrant species of economic insects over the past ten or fifteen years is attributable to an increase in importations of vegetables

[1] Sales of cryolite for 1943 amounted to 45 tons.

over that period, might not one answer to the problem be to produce more vegetables locally and thus reduce importations?

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